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Experimental Study on the Fire Performance of Superior LSF Wall Systems

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Abstract

Load bearing Light Gauge Steel Frame (LSF) walls are commonly made of conventional lipped channel sections and gypsum plasterboards. Recently, innovative steel sections such as hollow flange channel sections have been proposed as studs in LSF wall frames with a view to improve their fire resistance ratings. A series of full scale fire tests was then undertaken to investigate the fire performance of the new LSF wall systems under standard fire conditions. Test wall frames made of hollow flange section studs were lined with fire resistant gypsum plasterboards on both sides, and were subjected to increasing temperatures as given by the standard fire curve on one side. Both uninsulated and cavity insulated walls were tested with varying load ratios from 0.2 to 0.6. This paper presents the details of this experimental study on the fire performance of LSF walls and the results. Test results showed that the walls made of the new hollow flange channel section studs have a superior fire performance in comparison to that of lipped channel section stud walls. They also showed that the fire performance of cavity insulated walls was inferior to that of uninsulated walls. The reasons for this fire behaviour are described in this paper.

1. Introduction

Load bearing Light gauge Steel Frame (LSF) walls are being increasingly used in buildings due to their high strength to weight ratio, ease of fabrication and transportation. They are commonly made of conventional lipped channel section studs and gypsum plasterboards. Their important fire performances are usually evaluated by conducting experimental investigations (Alfawakhiri 2001, Feng and Wang 2005, Gerlich et al. 1996, Gunalan et al. 2013, Kodur and Sultan 2001 and Zhao et al. 2005). However, excessive time and costly testing of LSF walls have inhibited any innovations in LSF wall systems. In order to overcome this shortcoming, this research has proposed hollow flange channel section studs as load bearing elements in LSF wall systems. Hollow flange channel section known as LiteSteel beam is a structurally efficient section with two rectangular hollow flanges. Local, global and distortional buckling are eliminated to some extent when they are used as studs in LSF walls. The connectivity between the plasterboards and the steel studs is also enhanced in these wall systems as the screws penetrate through its inner and outer flanges. However, the fire performance of LSF walls made of hollow flange channel section studs is yet to be investigated. Therefore a series of fire tests was conducted on the new LSF wall systems made of hollow flange channel section studs and this paper reports the details of this study including the experimental method, outcomes and the interpretation of these outcomes.

2. Experimental Method

Five full scale fire tests (Table 1) were conducted on load bearing LSF walls made of hollow flange channel section (LiteSteel Beam 150 x 45 x 1.6 x 1.15 mm) studs (Figure 1(b)). These studs were connected to channel tracks at both ends. Figure 1(a) shows the dimensions of the steel frame. Test steel frames were lined on both sides by 16 mm thick gypsum plasterboards of dimensions 2100 mm width x 2400 mm length. The first and second layers of plasterboards were attached vertically and horizontally, respectively, as seen in Figure 2. The screw spacing was 300 mm, but at the joints it was 200 mm. The screws penetrated through both the inner and outer flanges of the LiteSteel beam studs. The studs were connected to the tracks using 10g wafer head screws while the plasterboards were connected to the studs using 8g bugle head screws.

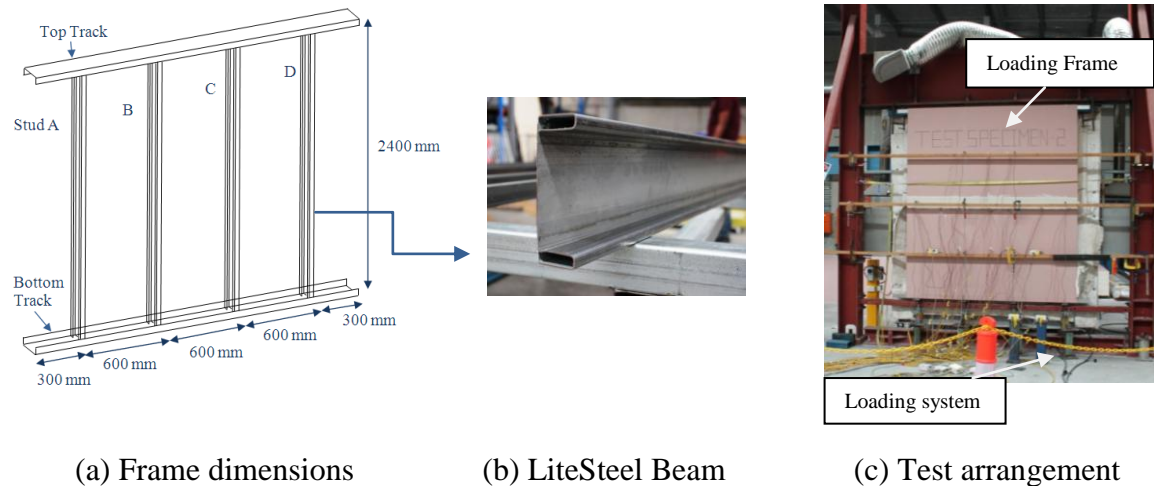


Figure 1: Test frame and set-up

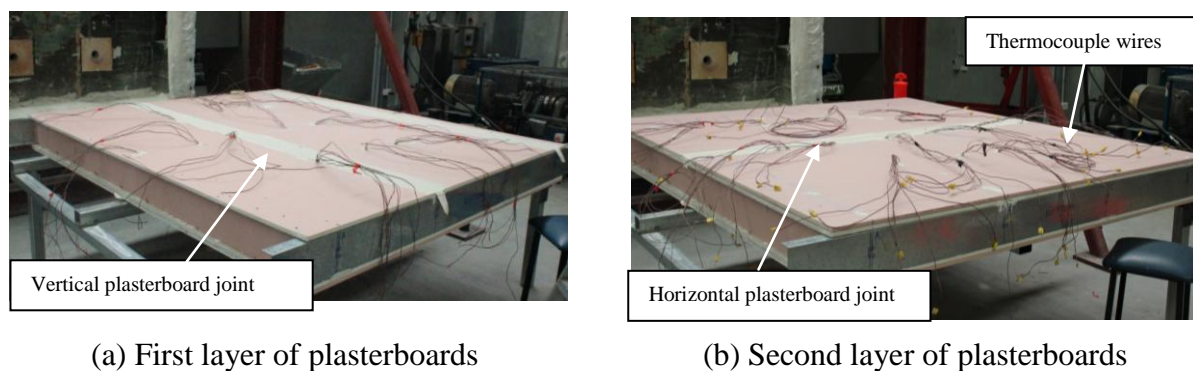


Figure 2: Ambient side plasterboard layers

K type thermocouples were attached to measure the temperatures of plasterboard and steel stud surfaces. The built wall was then placed in the loading frame system as shown in Figure 1(c). Each wall stud was loaded to a predetermined value at its centroid using a loading jack and this axial compression load was maintained during the fire test. The applied load was based on a ratio of the ambient temperature capacity of the 150 x 45 x 1.6 x 1.15 mm LiteSteel beam section stud. This load ratio was varied from 0.2 to 0.6 in the tests. Following the load application, the propane gas furnace available at QUT was used to apply the required temperature on the wall. Tests were conducted by exposing one side of the wall to the temperatures given by the standard fire curve given in AS 1530.5 (SA, 2005) until structural failure of the test wall occurred. LVDTs were used to measure the axial shortening and lateral

displacements at 0.25h, 0.5h and 0.75h. Figure 3 shows the locations of thermocouples across the test wall.

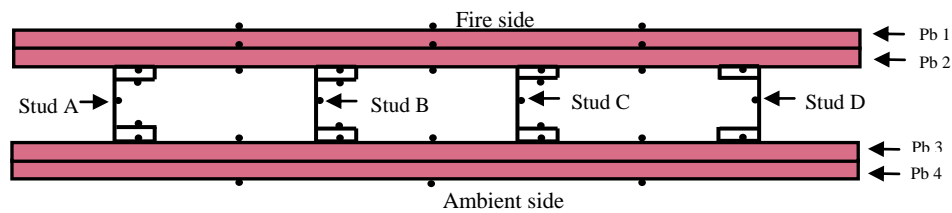


Figure 3: Locations of thermocouples across the wall

Table 1: Fire test details and outcomes

Test	Wall Configuration	Load Ratio	Failure Time (min.) (Struct/Insul)	Failure Mode	Failure Hot Flange Temperature (°C)
1		0.4	180	LTB	569
2		0.2	205	LTB	706
3		0.2	85/136	LTB	745
4		0.2	182	Major Axis buckling	739
5		0.6	138	LTB	525
A		0.2	111	Minor Axis buckling	555
B		0.2	54	Section failure	605
C		0.2	108	Major Axis buckling	560

Note: LTB – Lateral Torsional Buckling; Struct - Structural failure; Insul – Insulation failure

3. Test Outcomes and Observations

In all the tests continuous smoke with varying intensity was observed throughout the test. Water drops evaporating from the plasterboards were also observed on the top and bottom beams. Tests were terminated when the applied load could not be maintained. The load and lateral displacement versus time figures and the visual observations confirmed the failure. Figures 4 (a) and (b) show the lateral displacement versus time and the load versus time curves for Test 4.

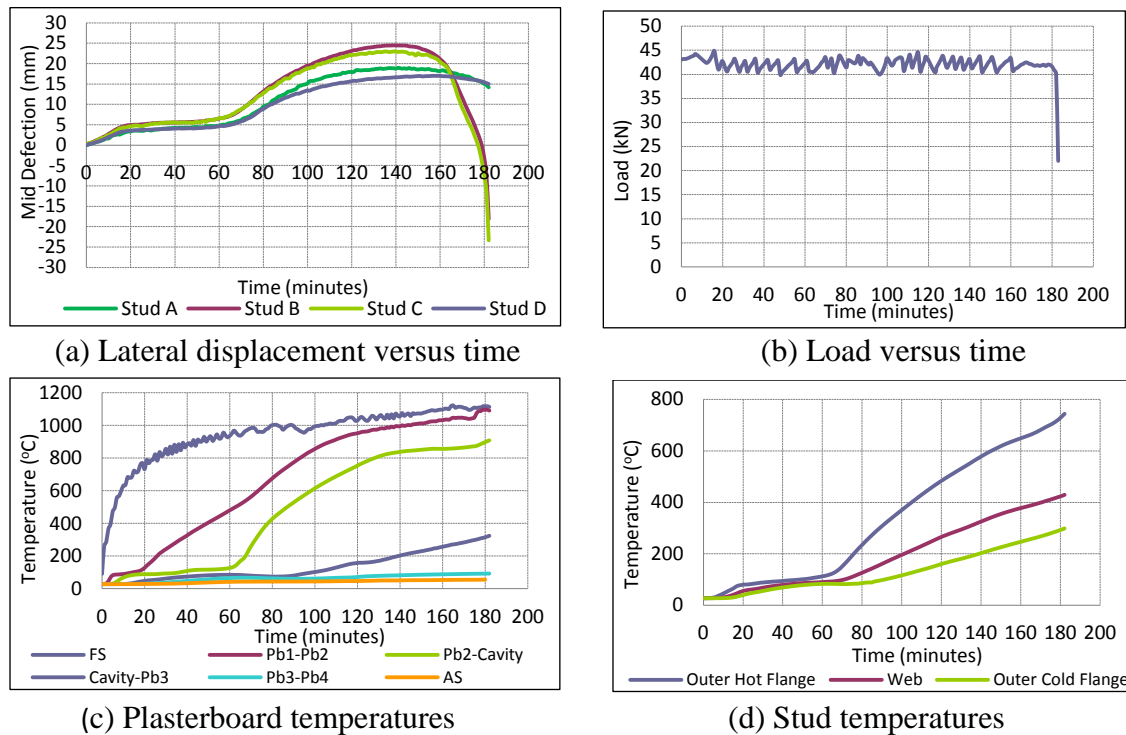


Figure 4: Test 4 results

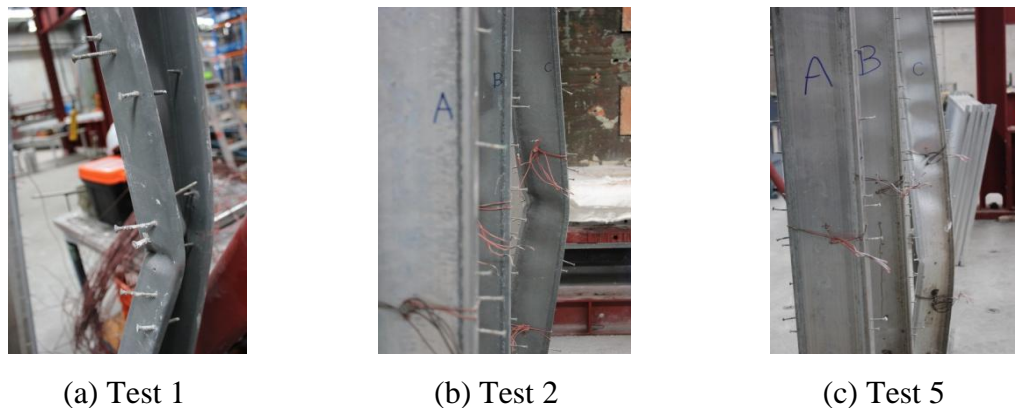


Figure 5: Failed studs

In all the tests the test wall moved towards the furnace progressively, and closer to the failure it moved away from the furnace rapidly and failed. However in Test 1, it failed by moving towards the furnace. Figure 5 shows the failed studs in Tests 1, 2 and 5. The failures in Tests 1, 2, 3 and 5 were due to lateral torsional buckling. In the failed studs, local buckling was also observed. Bending about the major axis and twisting about the minor axis were present while yielding of the compression flange was also observed. However in Test 4, the failure was due to major axis buckling. In the failed studs, local buckling and yielding of compression flange were also observed. However, these are based on the observations after the completion of the tests as studs were not visible during the fire test. The stud failure could have been initiated by a section failure, which possibly led to major axis and lateral torsional buckling. Numerical studies should be used to understand this fully. Figures 4 (c) and (d) illustrate the temperature development on the plasterboard and steel stud surfaces in Test 4. A horizontal plateau was observed in these graphs between 15 and 70 minutes because of the energy absorbed by plasterboards for dehydration reactions.

4. Discussion of Results

4.1 Effect of Load Ratio

In Tests 1, 2 and 5 the only variable was load ratio and Table 1 shows the reducing failure times with increasing load ratio. Figure 6 illustrates the temperature development along the failed steel stud and plasterboard surfaces. It shows that the temperature profiles of the plasterboard surfaces and the Outer Hot and Cold Flanges (OHF & OCF), and web of the failed steel stud were about the same in all three tests. This proves that the load ratio does not affect the temperature development in LSF walls. However, a closer look at the stud temperature profiles shows that there was a rapid temperature rise closer to failure. This occurred even in Test 5 which failed after 138 mins. Closer to failure, there would have been considerable movements of steel studs. This led to severe cracks in plasterboards, causing the steel stud temperatures to rise rapidly.

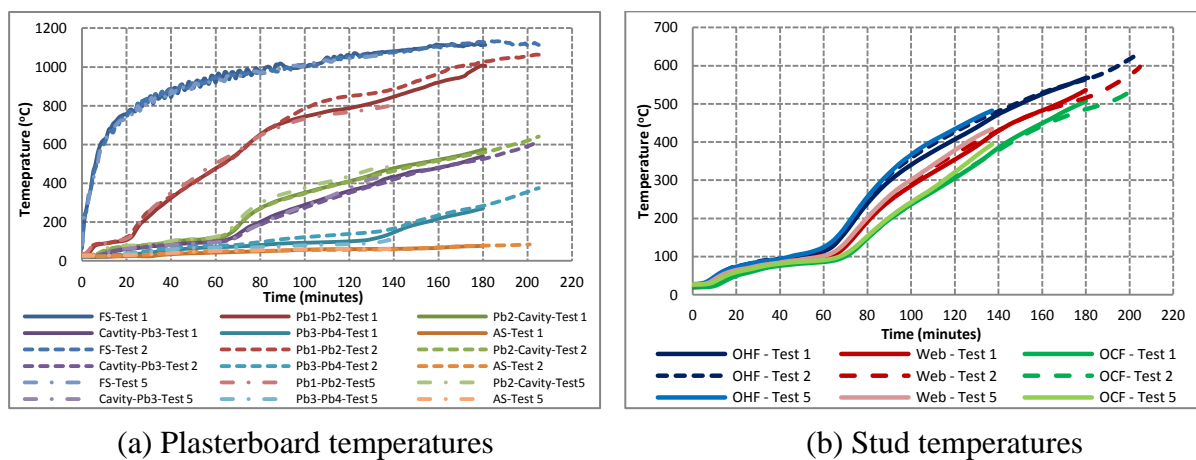


Figure 6: Time-temperature profiles of plasterboard and stud surfaces in Tests 1, 2 & 5

4.2. Insulated versus Uninsulated Walls

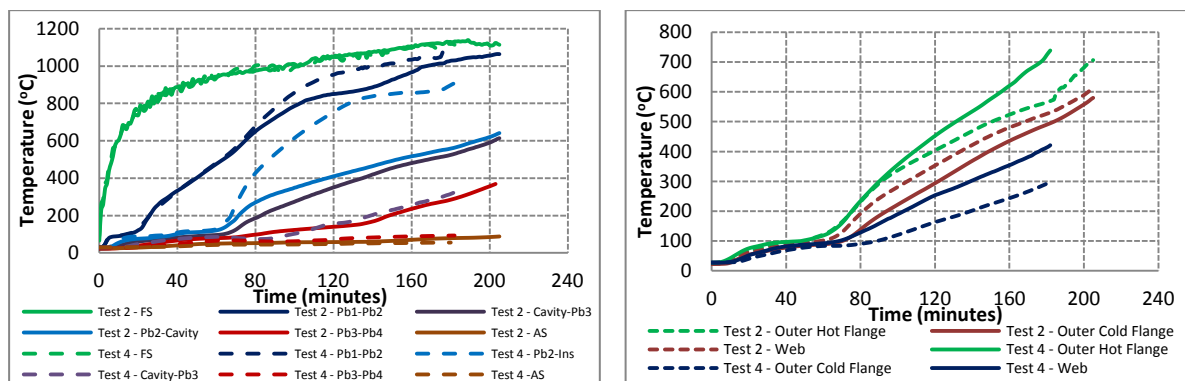


Figure 7: Temperature profiles of the plasterboard and stud surfaces with time

The only variable between Tests 2 and 4 was the provision of insulation. In Test 4, 50 mm thick insulation was placed inside the cavity. The temperature developments along the plasterboard and steel studs were the same only for the first 70 minutes. In Test 4, the fire side plasterboard temperatures were very high and ambient side plasterboard temperatures were very low in comparison to Test 2. Similarly, the outer hot flange temperatures were also very high while the outer cold flange temperatures were very low after 70 minutes in Test 4

(Figures 7(a) and (b)). This is because the effect of insulation on the plasterboard surface temperatures will be effective only after the completion of the dehydration reactions in the first and second layers of fireside plasterboards. It was only after 70 minutes the dehydration process was completed. Thereafter in Test 4, the insulation resisted the heat transfer through it. To counter balance it, the temperature on the fire side plasterboards (Pb1-Pb2 and Pb2-Cavity) will increase. Therefore, the temperatures of Pb1-Pb2 and Pb2-Cavity were higher in Test 4 than that observed in Test 2 after 70 minutes. The cavity insulation will resist the heat flow to the ambient side. Therefore, the temperature rise of Cavity-Pb3, Pb3-Pb4 and AS in Test 4 was lower than observed in Test 2.

4. 3. Superior Fire Performance of LSF Walls Made of Hollow Flange Section Studs

The fire performance of LSF walls made of hollow flange channel section studs was compared with the fire performance of LSF walls made of conventional lipped channel section studs. For this comparison Gunalan et al.'s (2013) test results of 90x40x1.15 lipped channel stud walls were used. Table 1 gives Gunalan et al.'s (2013) test details (Tests A, B and C) and their results

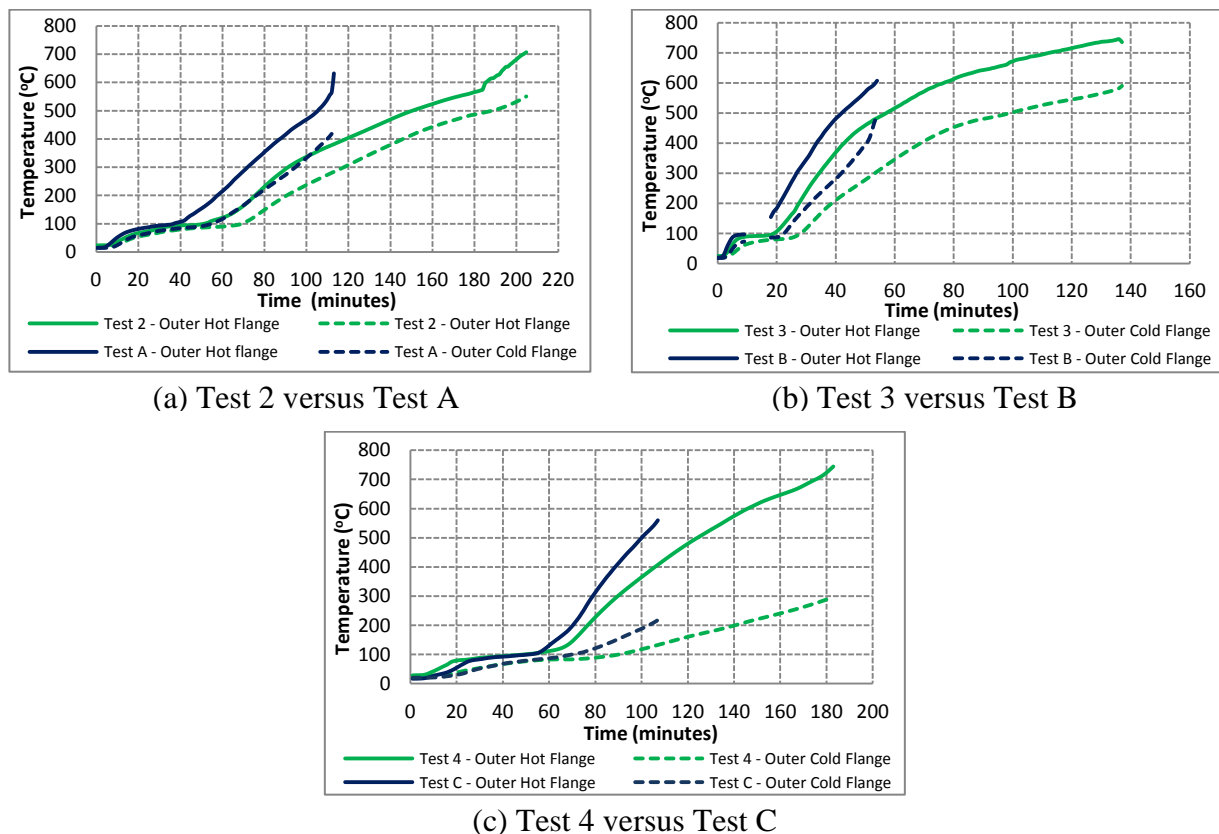


Figure 8: Comparison of outer hot and cold flange temperatures

The fire side temperatures produced by the furnace were the same in all the tests (Kesawan, 2013). The comparison of failure times of uninsulated LSF walls with dual plasterboards (205 mins in Test 2 versus 111 mins. in Test A), uninsulated LSF walls with single plasterboard (134 mins. in Tests 3 versus 54 mins. in Test B) and insulated LSF walls with dual plasterboards (182 mins. in Test 4 versus 108 mins. in Test C) in Table 1 clearly shows that LSF walls made of hollow flange channel section studs have a superior fire performance in comparison to those made of conventional lipped channel section studs. The outer hot flange and cold flange temperatures in these tests are compared in Figure 8.

The fire resistant ratings of LSF walls made of hollow flange channel section studs were almost twice that of the LSF walls made of conventional lipped channel section studs (see Table 1 and Figure 8). The reasons for the observed superior performance are given next.

- ❖ Elevated temperature mechanical properties (yield strength and elastic modulus) are likely to be higher for LiteSteel Beams than for lipped channel sections. The large difference observed between the outer hot flange temperatures at failure (600 versus 700°C) proves this (Figure 8).
- ❖ The temperature development in the stud cross section was slower in LSF walls made of hollow flange channel section studs than in those made of conventional lipped channel section studs. This may be because of the increased cavity size (90 to 150 mm) and the steel thickness (1.15 to 1.60 mm) of LSF walls made of hollow flange section studs. Further, vertical joints appeared to be weaker in the wall panels tested by Gunalan et al. (2013) in comparison to the wall panels tested in this study, which could have caused a rapid temperature rise.
- ❖ The depth of the hollow flange channel section (150 mm) used in the experimental series was higher than the depth (90 mm) of the conventional lipped channel section stud used by Gunalan et al (2013). Therefore, the thermal bowing deflection of hollow flange section stud wall was less than that in lipped channel section stud walls. This would have reduced the bending action in LSF walls made of hollow flange section stud and thus higher fire rating.
- ❖ In Tests A and B, a steep rise in both the hot and cold flange temperatures was observed closer to the failure. These failures had occurred suddenly after the plasterboard fall off. However, such steep rises in the outer hot and cold flange temperatures were not observed in Tests 2, 3 and 4. In Gunalan et al.'s (2013) tests, 6g screws were used to connect the plasterboards and steel studs and the screws penetrated only through the outer flanges of the conventional lipped channel section studs. However, in this experimental study, 8g screws were used and they penetrated through hollow flange section studs' two flange plates. Therefore the connectivity between the plasterboard and studs was improved in LSF walls made of hollow flange section studs. This would have delayed the plasterboard fall off and as a result fire resistant rating of LSF walls made of hollow flange channel sections studs increased.
- ❖ Improved fire performance of LSF walls made of hollow flange channel section studs needs to be further investigated using finite element modelling.

5. Conclusions

This paper has presented the details of five full scale fire tests of load bearing LSF wall systems made of hollow flange channel section studs and the results. Both cavity insulated and uninsulated wall systems were tested. Tests showed that load bearing LSF walls made of hollow flange channel section studs exhibited superior fire performance in comparison to that of LSF walls made of lipped channel section studs, irrespective of the type of wall configuration used. Fire performance of cavity insulated load bearing LSF walls was found to be poor in comparison to the uninsulated load bearing LSF walls. Effects of load ratio, insulation, and stud geometry on the fire performance of load bearing LSF walls including a number of time-temperature curves of steel stud and plasterboard surfaces are presented in this paper.

6. References

- Alfawakhiri F. (2001). *Behaviour of Cold-formed-Steel-framed Walls and Floors in Standard Fire Resistance Tests*, PhD Thesis, Carleton University, Ottawa, Ontario, Canada.
- Feng M and Wang YC. (2005). *An Experimental Study of Loaded Full-Scale Cold-Formed Thin-Walled Steel Structural Panels Under Fire Conditions*, *Fire Safety Journal*, Vol40. pp. 43-63.
- Gerlich JT, Collier PCR and Buchanan AH. (1996). *Design of Steel-framed Walls for Fire Resistance*, *Fire and Materials*, Vol20:Issue 2, pp. 79-96.
- Gunalan S, Kolarkar PN and Mahendran M. (2013). *Experimental Study of Load Bearing Cold-formed Steel Wall Systems under Fire Conditions*, *Thin-Walled Structures*, Vol64, pp.72-92.
- Kesawan S. (2013). *Fire Performance of Cold-formed Steel Wall Systems with Innovative Section Profiles*, PhD Thesis. School of Civil Engineering, Queensland University of Technology, Australia (In progress).
- Kodur VR and Sultan MA. (2001). *Factors Governing Fire Resistance of Load Bearing Steel Stud Walls*, *Proc. of the 5th AOSFST International Conference*, Newcastle, Australia, pp. 1-2.
- Standards Australia (SA), AS 1530.4, 2005, *Methods for Fire Tests on Building Materials, Components and Structures. Part 4: Fire-resistance Tests of Elements of Building Construction*, Sydney, Australia.